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UNITED STATES NAVAL ACADEMY
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APPLICATION OF PANELING METHODS
TO VORTEX-FIN INTERACTIONS

BY

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This work applies the Woodward USSAERO "C" code in a shortened form to the loads on an airfoil in the downwash field of a forward airfoil including the vortex impingement. The calculated pressure distributions are in general agreement with the experimental data, although both show the influence of the forward airfoil to be small in this case of a not-too-closely coupled line. The general trends of the loading on the rear fin both inboard and outboard of the vortex impingement are well demonstrated. The panel method can be used for this type of problem in aerodynamic loading.

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INTRODUCTION

The use of "panel" techniques to generate aerodynamic loading on arbitrary shapes is rapidly becoming the standard approach. This family of techniques employs a number of simplifying assumptions in the application of basic aerodynamic theory. Of particular interest is the specification of the Kutta condition which relates to the manner in which flow leaves a surface. It would appear that the manner in which the Kutta condition is specified on a forward lifting surface would greatly affect the flow field in the vicinity of a trailing lifting surface. This work examines the flow field on such a surface as generated by a typical modern panel technique and compares that with experimental data being taken as part of another project.

DISCUSSION

The location of source, doublet and vortex aerodynamic singularities of arbitrary wing-body shapes in small surface panels has generally become known as the panel method. This technique has removed much of the configuration restrictions associated with previous superposition methods, particularly with subsonic flow, and thus has become a common analysis technique. Numerous demonstrations of its usefulness have been generated, and the recent literature is filled with such results.

A lesser number of more fundamental examinations are available which look at critical features of the approximations. Typical of these is the examination of the effect of various methods of implementing the Kutta condition on lifting surfaces as done by Hess[1]. In this study, it is noted that three specifications can be made of the flow leaving the trailing edge of a lifting surface as follows:

(a) The stream direction can be specified.

(b) The surface pressures, or velocities, can be specified.

(c) The source densities can be made zero.

Of these boundary specifications, type (a) or (b) is generally used in typical approaches of the day. By an examination of the general nature of the flow in the near vortex wake of the lifting surface and by a detailed calculation of the lift coefficient of a classic airfoil, the conclusion is made that a specification of the type (b) is to be slightly preferred. Both type (a) and (b) are in common use, however.

Maskew and Woodward[2] have carried this investigation a little further with the same general conclusion, but the differences are slight and at the present deal only with the generating lifting surface. Woodward[3], in developing operational codes, has successfully employed both criteria.

The large scale panel code developed by Woodward[4], known as USSAERO, has undergone numerous modifications and exists now in several forms. One of the forms, employing criterion (a), has been implemented at the U. S. Naval Academy in a much shortened form very suitable for low speed studies of the basic formulation.

At the same time, Gillerlain and Yanta[5] have been involved in a long term study of the three-dimensional flow field around a lifting surface due to another lifting surface upstream. This work has been examining the effects of a vortex upstream impinging on a downstream fin. The studies have included pressure and tuft studies on the downstream fin and laser Doppler velocimeter data on the flow field. The configuration in general use can easily be converted to a more specific nature representative of useful aerodynamic purpose.

RESULTS

The configuration used to collect experimental data in the wind tunnel is shown in Figure 1. A forward lifting surface with a 0015 airfoil shape was set at 5° angle of attack. A second surface was set 24 inches downstream at a zero angle of attack with respect to the free stream. This surface had been a flat plate with round leading and trailing edges but now had an airfoil-like fairing fitted to the trailing edge. The front foil extended 8 1/4 inches from the tunnel wall, and the rear foil extended 12 1/8. Thus, the vortex from the front foil was expected to impinge directly on the rear. A number of pressure measurement locations were available on the rear foil to determine the effect of this impingement. For all data, the tunnel velocity was nominally 150 feet per second.

Theoretical pressure distributions on the rear foil were generated by the Woodward USSAERO "C" version of panel method as implemented in a shortened form on the U. S. Naval Academy computer system. During the course of these calculations, it was found that the multiple lifting surface configuration does not run in USSAERO with the most desirable thick wing option. NASA Langley, the contracting agency for this code, has been advised of this and has confirmed the defect in the parent code. They now have work underway to alleviate this problem. In the meantime, this study was carried out using a planar boundary condition on the lifting surface. Individual studies of the surface pressure were carried out for the differences between the two options, and they were negligible in the range of measurement.

Results for the calculated and experimental pressure coefficients on the rear foil are shown in Figures 2 and 3 for the 6.2 in. span station, Figures 4 and 5 for the 8.1 in. span station and Figures 6 and 7 for the 10.1 in. span

station. Experimental data appears as the circular symbols. Side-by-side interlocking symbols indicate pressure coefficients at that location having the same value with and without the front foil. Otherwise, the symbols give the proper relation of the data.

Two things are immediately evident on a general examination of the theoretical and experimental data. First, the calculated pressure coefficients for this strange airfoil shape are generally in close agreement with the experimental data. Second, there seems to be very little difference shown by either theoretical or experimental data between the rear foil pressure with and without the front foil. Having made these two statements, it seems almost fruitless to continue to extract more information from the results. Nevertheless, some trends can be cited even though the trends are sometimes of the same order of magnitude as the data uncertainty.

At the most inboard measuring station, seen in Figures 2 and 3, the theoretical pressures tend to be less negative on the top surface and more negative on the lower surface when the front foil is present. This trend, at least on the forward portion of the airfoil, has some support from the experimental data and would be expected from physical reasoning. This would say the downwash field from the front foil would introduce a negative local angle of attack on the rear foil with its attendant down load.

At the intermediate measuring station, shown in Figures 4 and 5, the picture is less clear. The theoretical pressure distribution has a negligible change on the upper surface due to the presence of the front foil, and the lower surface has only a small change in load. Experimentally, the change is not too significant and not in consistent directions.

At the outer measurement station, shown in Figures 6 and 7, there appears to be some reversal of the previous trend. Calculated pressures, at least in

the leading edge vicinity, are tending to be more negative on the top surface than on the bottom. There is experimental evidence of this too, which indicates less down load on the portion of the rear foil outboard of the tip of the front foil. Simple physical reasoning would also lead to velocity components of the tip vortex tending to reverse the downwash field in this outer region.

This is summarized in Figure 8 for the three measuring stations. This ΔC_p, the difference between the upper and lower pressure coefficients, is a direct measure of the asymmetric loading due to the front foil. Both the trends and the order of magnitude of the changes are consistent between the calculational and experimental data for the inboard and outboard stations. For the impingement station, the results are erratic and inconclusive.

CONCLUSIONS

A panel aerodynamic technique has been used to generate the influence of a forward airfoil shape at angle of attack on a trailing foil having a greater span. The theoretical results are compared with experimental data. Both the theoretical and experimental results show that the effect of the forward airfoil is very small. Even so, the trends generated by this calculational method are generally in agreement with the experimental data at least in the vicinity of the leading edge. One could conclude tentatively that a detailed application of a panel technique could be effective in looking generally at interference of lifting surfaces.

A greater amount of work needs to be done with this basic configuration. The distance between the surfaces needs to be shortened to a closer coupled configuration and the angle of attack needs to be increased. This should increase the differences to more significant values, and accentuate any comparison of the manner boundary conditions are imposed in the theoretical approach.

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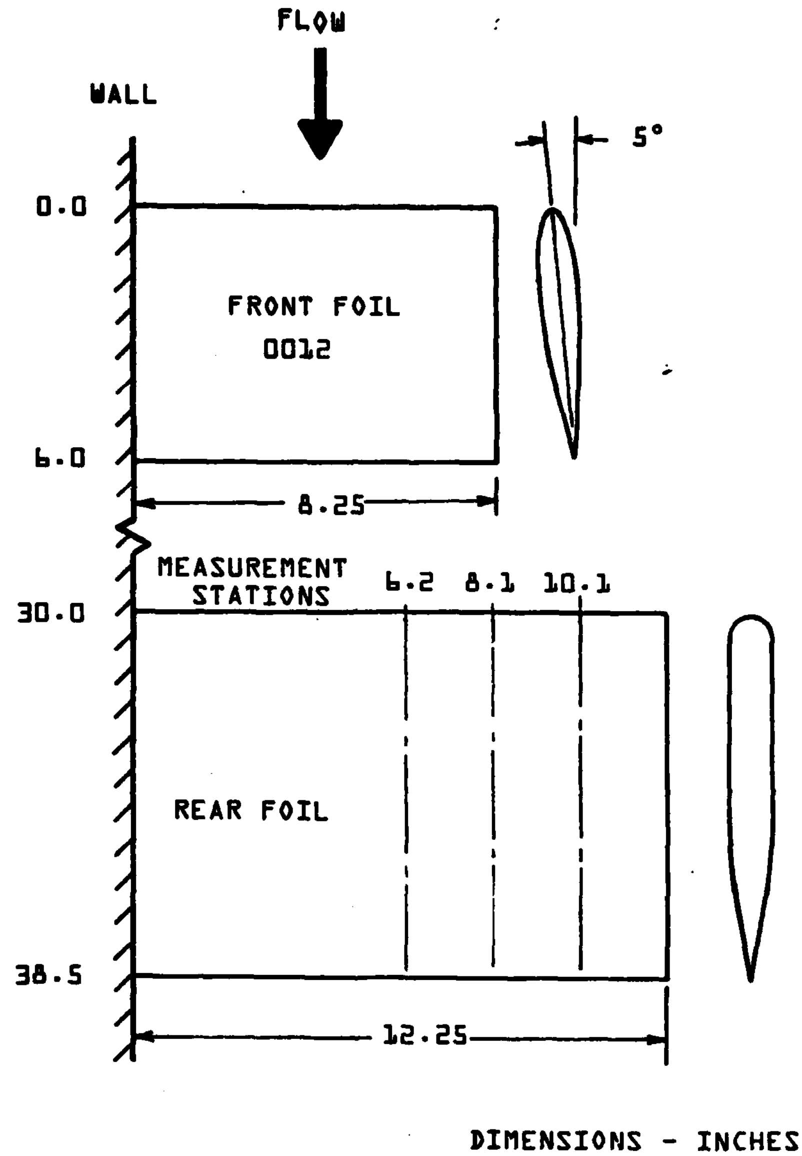


FIGURE 1 - GENERAL CONFIGURATION

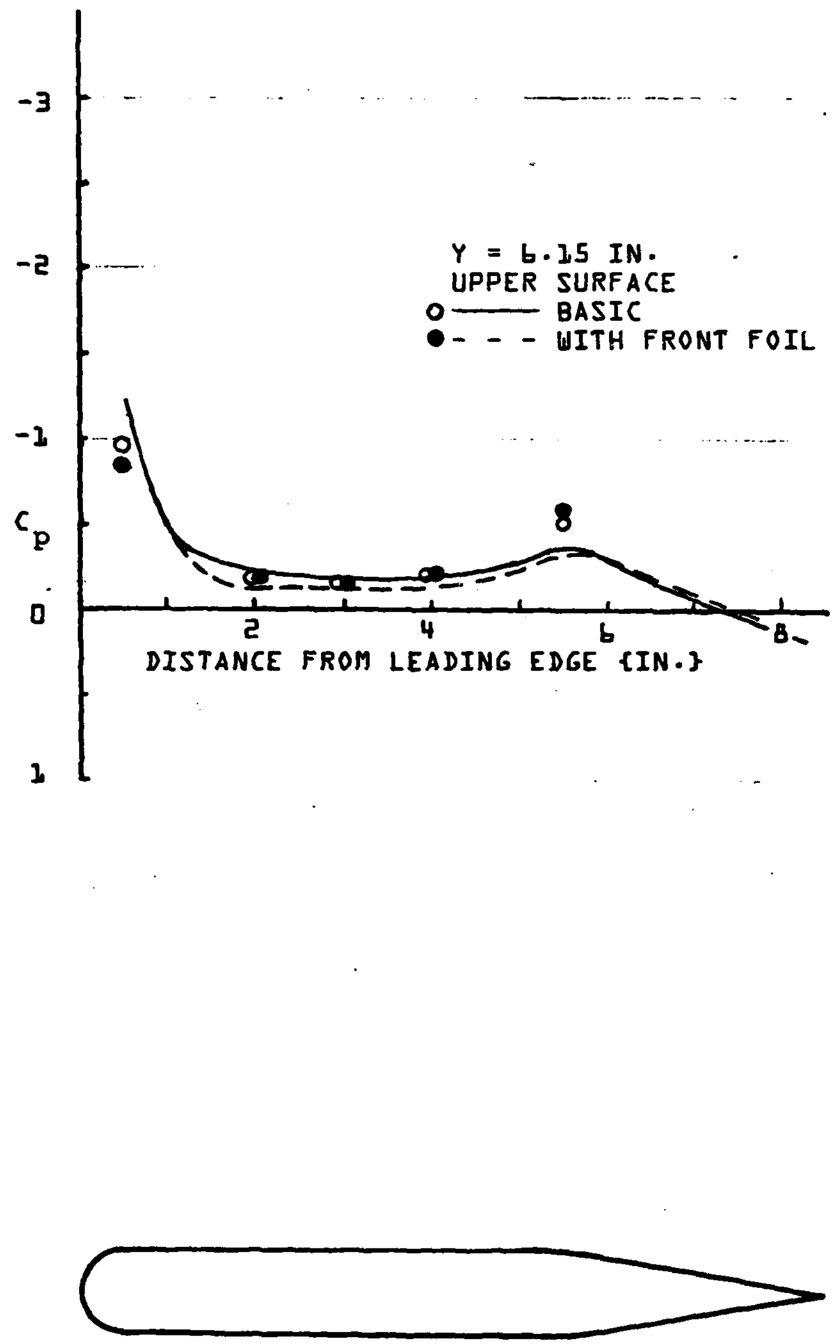


FIGURE 2 - THEORETICAL AND EXPERIMENTAL PRESSURE INBOARD OF VORTEX IMPINGEMENT, UPPER SURFACE

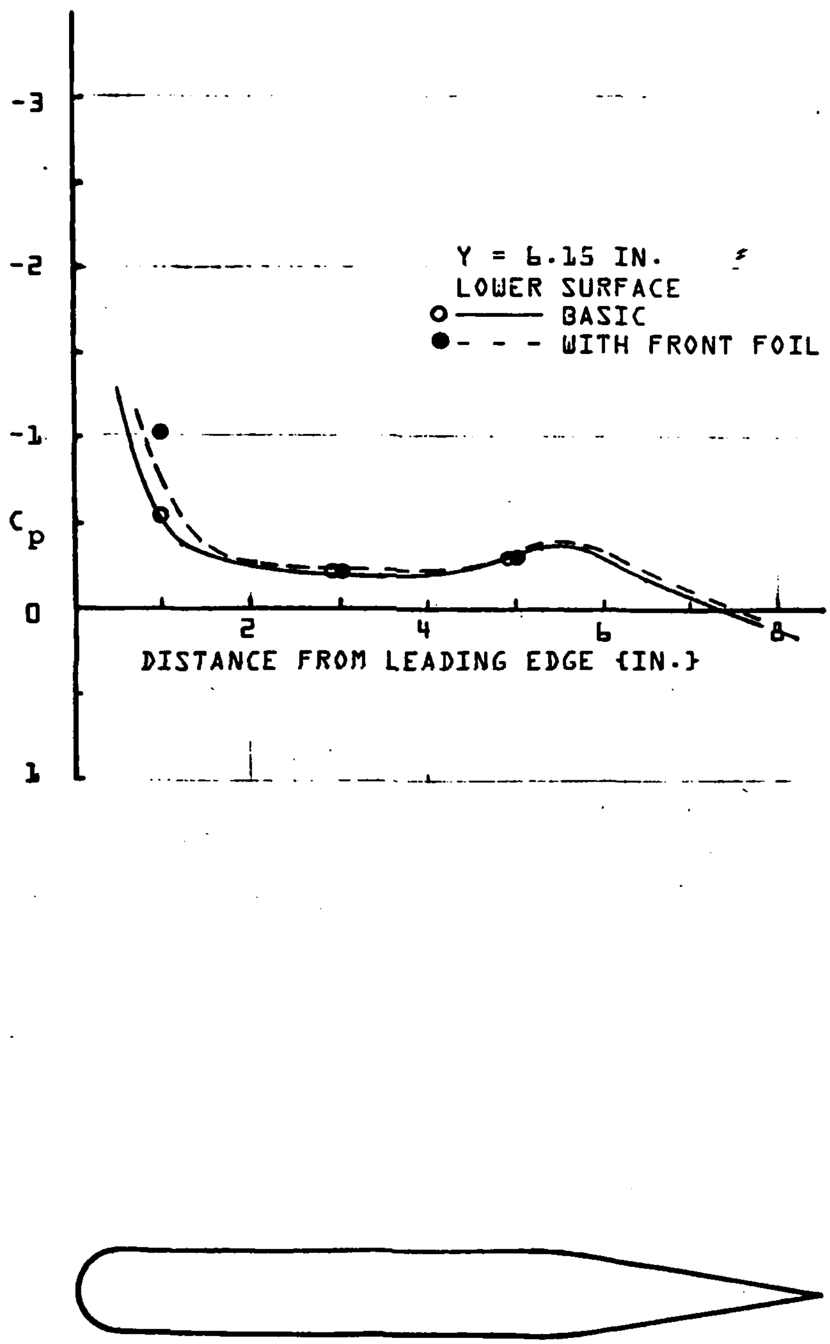
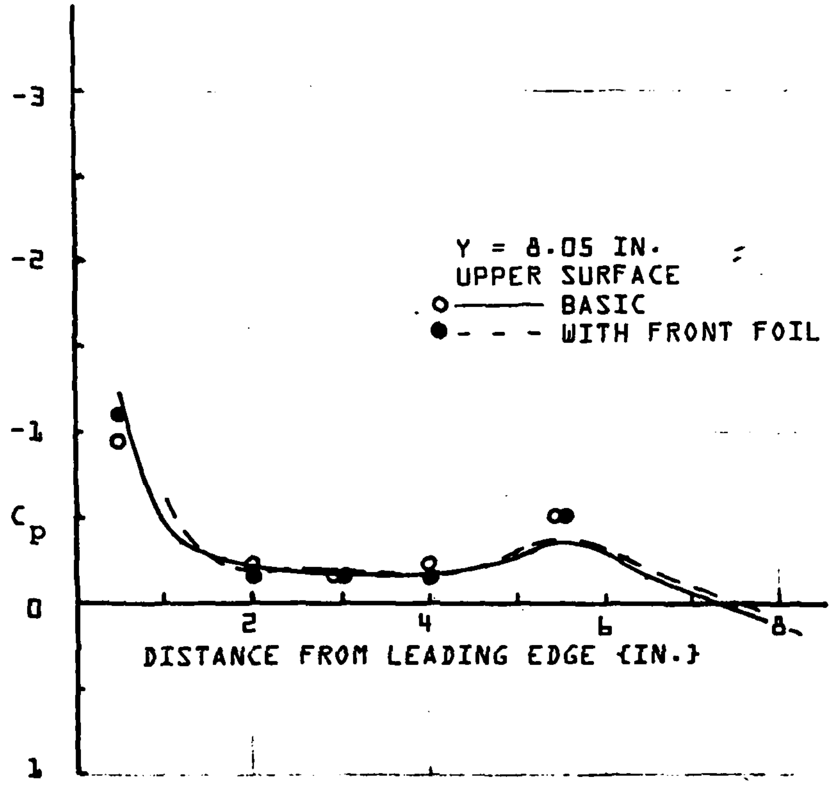


FIGURE 3 - THEORETICAL AND EXPERIMENTAL PRESSURE INBOARD OF VORTEX IMPINGEMENT, LOWER SURFACE



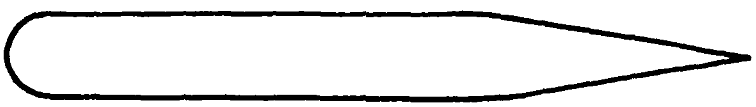
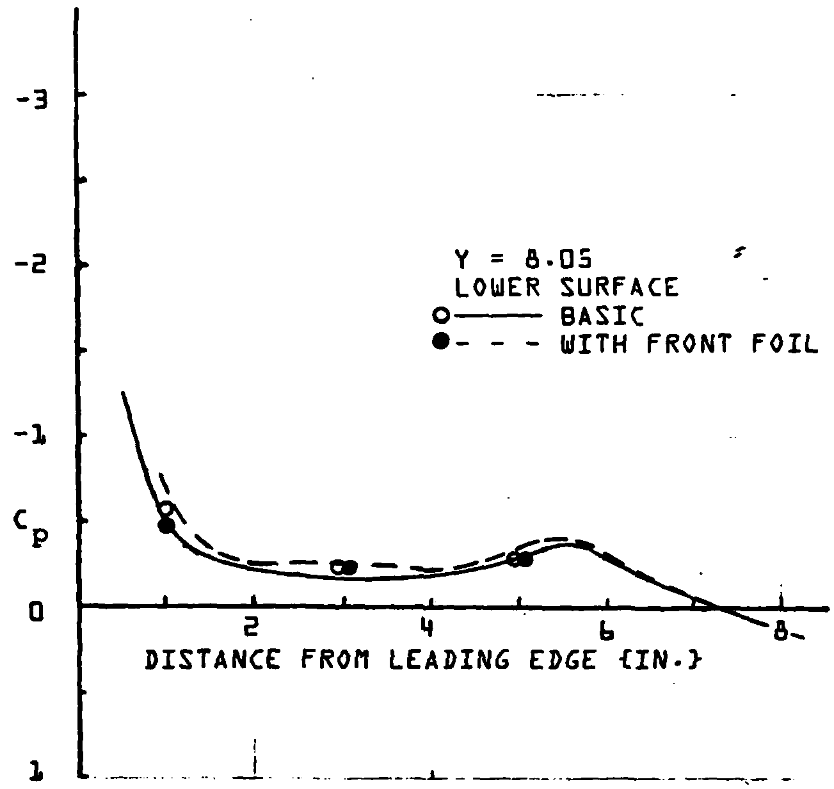


FIGURE 4 - THEORETICAL AND EXPERIMENTAL PRESSURE IN THE VORTEX IMPINGEMENT REGION - UPPER SURFACE



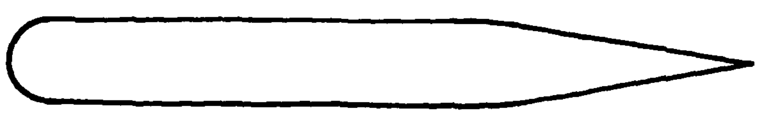
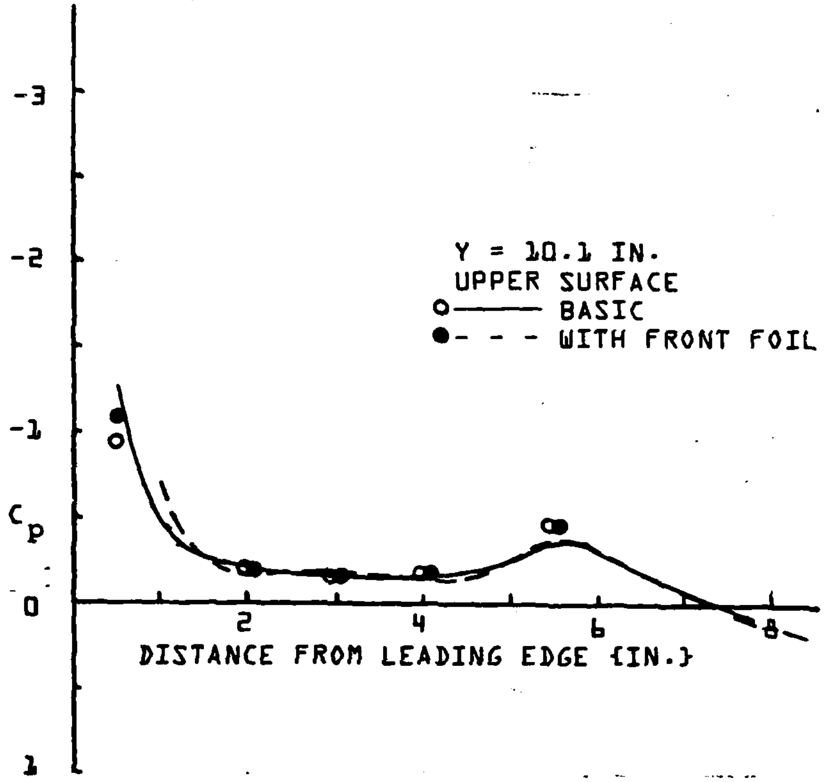


FIGURE 5 - THEORETICAL AND EXPERIMENTAL PRESSURE IN THE VORTEX IMPINGEMENT REGION - LOWER SURFACE



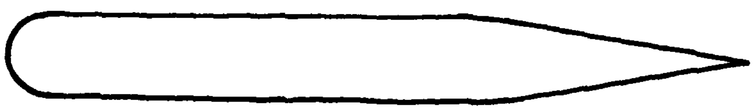
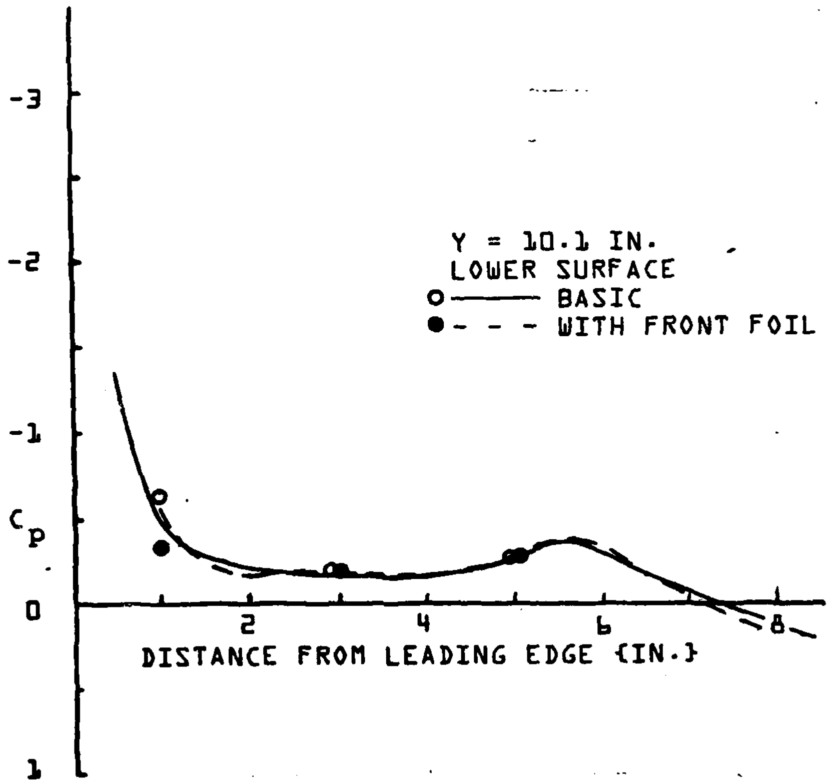


FIGURE 6 - THEORETICAL AND EXPERIMENTAL PRESSURE OUTBOARD OF VORTEX IMPINGEMENT, UPPER SURFACE



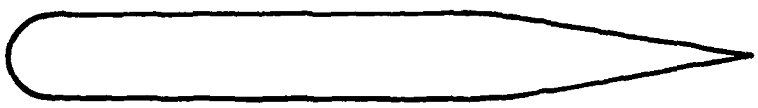


FIGURE 7 - THEORETICAL AND EXPERIMENTAL PRESSURE OUTBOARD OF VORTEX IMPINGEMENT, LOWER SURFACE

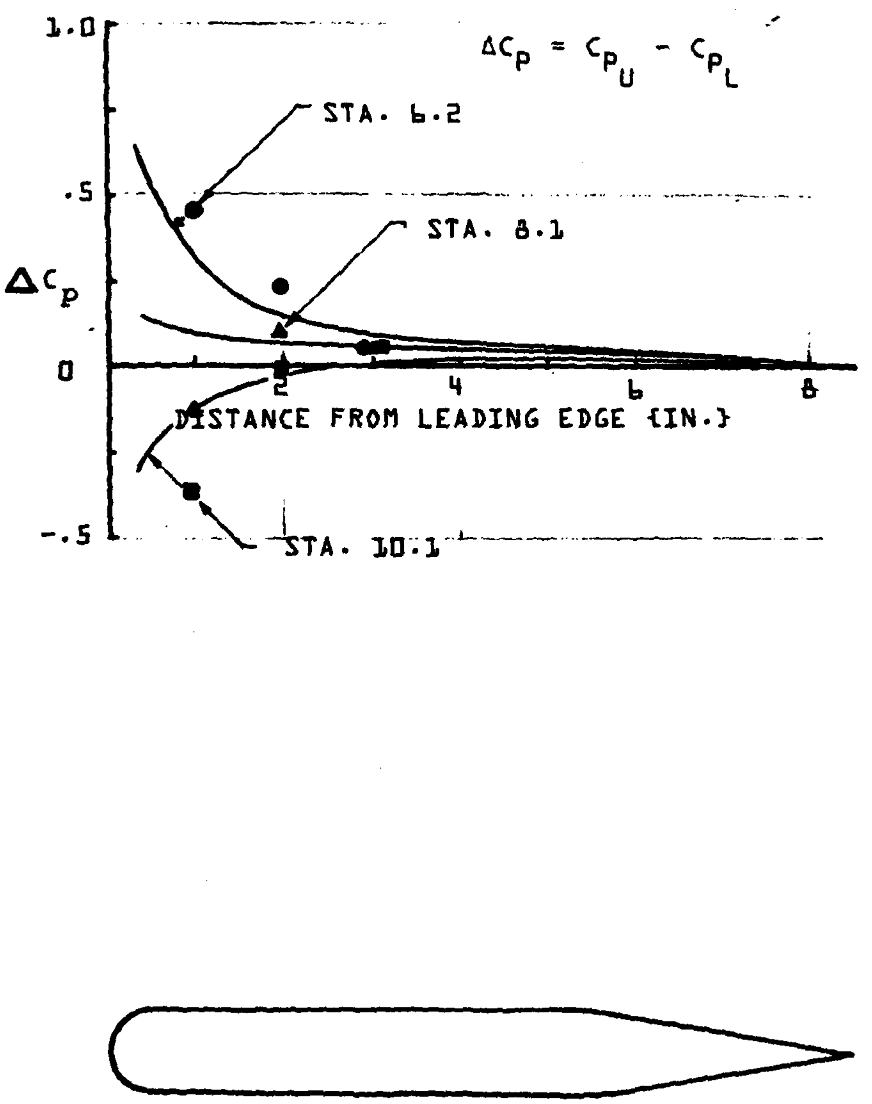


FIGURE 8 - CHANGE IN REAR FIN LOADING WITH VORTEX IMPINGEMENT